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REFRIGERATION SYSTEM

Field of the Invention

The present invention refers to a refrigeration system that uses a Stirling machine as a source of thermal energy to be transferred to environments located outside and spaced in relation to the compressor, particularly to the heat exchangers (heads) thereof.

Background of the Invention

Stirling machines have been known for many years, operating in several applications. They are widely used as systems to produce movement (motors) and in the field of energy generation, by using heat sources. Stirling machines are also used to refrigerate environments, or in refrigeration systems, mainly in systems with low capacity (below 100W, in ASHRAE check point) and low storage temperatures (lower than -100°C).

Such machines comprise a hermetic shell, within which is mounted a motor, which can be of the linear type driving a piston that compresses the gas existing inside the shell. There are further provided, in the interior of the hermetic shell, heat exchangers that are coupled to a hot external heat exchanger, or hot head, and to other heat exchanger coupled to a cold external heat exchanger, or cold head, both heat exchangers being produced in a metallic material with good thermal conductivity, which allows them to be capable to reject heat to the environment external to the machine and to absorb heat from another environment, respectively.

The Stirling machines generally have the heat of its hot head directed to a heat releasing environment, and its cold head is associated with a refrigeration system to refrigerate a determined environment.

The Stirling machine works by using, for example,

helium as a refrigerant fluid, but other alternatives of refrigerant fluid may be used, such as hydrogen, or nitrogen, as described in Patent US 5,927,079.

Stirling machines need auxiliary devices to allow transferring heat from its hot heat exchanger to the environment whereto heat is desired to be transferred, as well as devices that allow heat to be absorbed from the environment requiring to be refrigerated through the cold head. There are known in the art some devices that allow effecting such heat transfers.

The known prior art presents different alternatives to make possible said transfer, such as: employing auxiliary heat exchangers of the thermosiphon type, as taught in Patent US 6,347,523; providing fins on the heads and using an auxiliary air movement system; using heat pipes; using a fluid pumping system employing pumps driven by one of the oscillating, mechanical, or electrical movements, among others.

In one of the known prior art solutions in which the Stirling machines are used in a refrigeration system, as described in Patent US 5,927,079, the refrigeration of a determined environment is carried out by pumping a refrigerant fluid, under low temperature, which is refrigerated by heat exchange while passing around the cold head of the Stirling machine to an evaporator provided in the environment to be refrigerated. In this construction, the fluid under low temperature and refrigerated in the cold head of the Stirling machine is conducted through the pipes of the evaporator by using pumping means disposed between the Stirling machine and the evaporator. In this construction, the removal of heat from the hot head of the Stirling machine is achieved by the circulation of water in a closed loop that passes through said hot head of the Stirling machine, which circulation is also achieved

by action of a pump element mounted in the heat removing loop.

However, these known solutions present some disadvantages, such as in the systems employing the thermosiphon as the working principle, the need to level the component parts, such as pipes and heat exchangers.

In the case of the known solutions that use fins on the heads and heat exchange by air, the disadvantage resides in the fact that high heat transfer capacities are not possible to be achieved. In said systems, a saturation limit in relation to the heat transfer capacity is easily reached. This is due to the efficiency saturation of the fins with the increase of their length and/or decrease of the distance therebetween, or even due to the impossibility of finding air movement equipments with sufficient capacity to allow reaching the pressure and flowrate levels required for determined heat transfer capacities. In addition, such solutions cause an increase in the level of vibrations of the refrigeration system and a reduction of reliability, as a function of the large quantity of the existing moving parts. The known solutions that use heat pipes further present the following disadvantage: high pressure loss of the system due to the necessary provision of a porous material outside the evaporation region, which reduces the capacity to transfer heat at great distances.

Objects of the Invention

Thus, it is an object of the present invention to provide a refrigeration system that uses a Stirling machine, which allows achieving an efficient refrigeration of environments, without the problems existing in the known solutions, such as low heat

transfer capacity, pressure loss in the system, and low reliability.

Another object of the present invention is to provide a refrigeration system such as mentioned above, which reduces the need to level component parts of the system, such as pipes and heat exchangers.

A further object of the present invention is to provide a system such as proposed above, which presents minimum moving parts, reducing the possibility of occurring vibration in the refrigeration system.

Summary of the Invention

These and other objects are achieved through a refrigeration system of the type which comprises: a Stirling machine having a heating portion and a refrigerating portion; a refrigerating chamber; a first thermal energy transfer device operatively associated with the refrigerating portion and with the refrigerating chamber, so as to transfer the heat from the latter to the refrigerating portion by means of a circulating fluid; a second thermal energy transfer device, operatively associated with a heat receiving means, external to said machine, and with the heating portion thereof, so as to transfer heat from the heating portion to the heat receiving means by means of a circulating fluid.

According to the invention, the first thermal energy transfer device comprises at least one capillary pump mounted in the refrigerating chamber, in order to evaporate, by the heat absorbed from the latter and by action of the capillarity induced by said fluid passing through the capillary pump, the circulating fluid received in said capillary pump; a condenser operatively coupled to the refrigerating portion of the Stirling machine, in order to condense the

circulating fluid received, in the gaseous state, from the capillary pump; and pipes to conduct in a closed loop the circulating fluid, in the liquid state, from the condenser to the capillary pump and, in the gaseous state, from the latter to the condenser.

Brief Description of the Drawings

The invention will be described below, with reference to the enclosed drawings given by way of example for a preferred embodiment, and in which:

Figure 1 is a schematic perspective view of the refrigeration system of the present invention, with the Stirling machine being operatively associated with an environment to be refrigerated;

Figure 2 is a schematic perspective view of a construction for the thermal energy transfer device of the refrigeration system of the present invention;

Figure 3 is a longitudinal sectional view of a first construction for a capillary pump of the present invention driven by the heat removed from the environment to be refrigerated;

Figures 4, 5 and 6 are cross-sectional views of the first construction for the capillary pump respectively taken according to lines IV-IV, V-V and VI-VI of figure 3;

Figure 7 is a somewhat schematic partially cut perspective view of a second construction for the capillary pump of the present invention driven by the heat removed from the heating portion of the Stirling machine;

Figure 8 is a diametrical cross-sectional view of the second construction for the capillary pump illustrated in figure 7;

Figure 9 is a cross-sectional view of the capillary pump of figure 7, taken according to line IX-IX of figure 8; and

Figure 10 is a cross-sectional view of the capillary pump of figure 7, taken according to line X-X of figure 8.

Description of the Illustrated Embodiment

The refrigeration system of the present invention comprises a Stirling machine 1, for example of the type which uses a linear motor operatively associated with a first thermal energy transfer device 2 and a second thermal energy transfer device 3, one of them being operatively coupled to a refrigerating chamber 4. In the example of the illustrated construction, the first thermal energy transfer device 2 is the one associated with the refrigerating chamber 4.

The Stirling machine 1 comprises, conventionally, a heating portion 1a and a refrigerating portion 1b, each one operatively connected to one of the first and second thermal energy transfer devices 2, 3, as described below.

According to the present invention, the first thermal energy transfer device 2 contains a first circulating fluid to transfer thermal energy between the refrigerating portion 1b of the Stirling machine 1 and the refrigerating chamber 4, the second thermal energy transfer device 3 containing a second circulating fluid to transfer thermal energy between the heating portion 1a of the Stirling machine 1 and a heat receiving means, which is usually the atmosphere or ambient air, maintaining a certain space from the machine.

In a way of carrying out the present invention, the first and the second circulating fluids are the same and defined for example, but not exclusively, by at least one of the elements selected from the group consisting of ether, water, and alcohol. It should be pointed out that other types of circulating fluids are

possible, without altering the scope of protection claimed herein.

According to the present invention, in one or in both the first and the second thermal energy transfer devices 2, 3, there is provided at least one capillary pump, to be described below, through which passes a respective circulating fluid received in the liquid state and which, during its passage through said capillary pump, is submitted to a phase change, passing from the liquid state to the gaseous state. Each one of said first and second thermal energy transfer devices 2, 3, also comprises a respective heat exchanger, in which the respective circulating fluid coming from the capillary pump and in the gaseous state is submitted to a phase change, passing to the liquid state.

According to the present invention, the first thermal energy transfer device 2 comprises at least one capillary pump 10, associated with the refrigerating chamber 4 and presenting: a hermetic shell 11 provided with an inlet 11a for the circulating fluid in the liquid state, and with an outlet 11b for the circulating fluid in the gaseous state and which is disposed spaced from the inlet 11a and separated from the latter by a porous means 12, lodged inside the shell 11 and through which the circulating fluid passes in its path from an inlet side to an outlet side of the porous means, as it changes from the liquid state to the gaseous state by the evaporation provoked by a heat source to which a region of the shell 11 is exposed, and also by action of the pressure loss generated upon the fluid passing through the porous material, against which is seated the outlet side of the porous means 12 where the outlet 11b is provided.

In the first thermal energy transfer device 2, the heat source is represented by the air, which passes, preferably in a forced airflow, through the interior of the refrigerating chamber 4, in which is mounted the capillary pump 10, or the assembly of capillary pumps 10, driven by the heat removed from any environment to be refrigerated. In this construction, the circulating fluid in the liquid state supplied to the capillary pump 10 comes from a heat exchanger in the form of a condenser 20 operatively coupled to the refrigerating portion 1b of the Stirling machine 1 to transfer to said refrigerating portion 1b the heat which the circulating fluid absorbed upon changing to the gaseous state in the capillary pump 10, condensing said circulating fluid and allowing it to return, in the liquid state, back to the inlet 11a of the shell 11 of the capillary pump 10.

As it can be noted in figures 1 and 2, the capillary pump 10, or the assembly of capillary pumps 10, are connected to the condenser 20 by a pair of pipes 30, 40, one of the latter being coupled to the inlet 11a for the circulating fluid in the liquid state in each capillary pump 10, while the other pipe is coupled to the outlet 11b for the circulating fluid in the gaseous state of each capillary pump 10.

In the illustrated embodiment, the first thermal energy transfer device 2 comprises a plurality of capillary pumps 10, disposed parallel in relation to the respective closed loop of circulating fluid and which are mounted inside the refrigerating chamber 4, so as to operate, in conjunction, as an evaporator to evaporate the circulating fluid, using the heat of the airflow F flowing through said refrigerating chamber 4.

In the construction illustrated in figures 2-6, each

capillary pump 10 has its shell 11 defined by an elongated pipe, constructed in any adequate material and presenting high thermal conductivity, said shell 11 being transversally incorporated to a plurality of heat exchanging fins 13, which are parallel to and spaced from each other and arranged generally parallel to the direction of the airflow F to be refrigerated and which flows through said evaporator defined by the plurality of capillary pumps 10.

In said embodiment of figures 2-6, the shell 11 in the form of an elongated pipe has an end defining the inlet 11a and the opposite end defining the outlet 11b of the circulating fluid, said inlet 11a and outlet 11b being separated from each other by a porous means 12, affixed to the inside of the shell 11 and also presenting a tubular shape, with an open end adjacent to the inlet 11a to receive, in the interior of the porous means 12, the circulating fluid in the liquid state, and with a closed opposite end adjacent to the outlet 11b of the shell 11. The porous means 12 has its external diameter dimensioned to allow it to be tightly seated in relation to the internal surface of the shell 11.

In order to allow the circulating fluid to radially traverse the annular thickness of the porous means 12 while evaporating to the gaseous state, and to allow said fluid to be captured to continue its path through the outlet 11b and through the pipe 40 toward the condenser 20, longitudinal passages 12a are formed, between the porous means 12 and the shell 11, having an end that is closed by the porous means 12 itself near the inlet 11a, and an opposite end opened to the outlet 11b.

In the illustrated embodiment, the longitudinal passages 12a are obtained by the provision of

respective longitudinal grooves in the external surface of the porous means 12. However, it should be understood that said grooves could be also provided along the internal surface of the shell 11.

Considering that the condenser 20 of the first thermal energy transfer device 2 transfers heat from the circulating fluid in the gaseous state to the refrigerating portion 1b of the Stirling machine 1, this condenser 20 preferably presents a cylindrical annular shell 21 with an internal wall seated around the refrigerating portion 1b, so as to be able to transfer heat, by conduction, to the latter.

The internal construction of the condenser 20 can be effected in different manners, provided that it allows achieving an efficient thermal exchange between the circulating fluid and the refrigerating portion 1b of the Stirling machine 1.

Anyway, the shell 21 of the condenser 20 is provided with an inlet 21a and an outlet 21b, which are respectively connected to the pipes 30, 40 and the inlet 21a and the outlet 21b are interconnected inside the shell 21 by any connecting means, such as a coil immersed in a heat conducting means, for example a liquid in a simultaneous direct contact with the internal wall of the shell 21 and with the connecting means that connects the inlet 21a to the outlet 21b.

As already mentioned in relation to the evaporator of the first thermal energy transfer device 2, the condenser 20 should have its shell 21 and its internal component parts constructed in a material of high thermal conductivity and which resists both the working conditions of the system and the circulating fluid that is used.

According to the description above, the first thermal energy transfer device 2 is constructed to remove the

heat from the refrigerating chamber 4 by means of a circulating fluid that is impelled only by one evaporator, operating jointly with a condenser and in the form of an assembly of parallel capillary pumps 10. The condenser is mounted to the refrigerating portion of the Stirling machine that works as an absorbing source of the heat removed by the evaporator from the environment to be refrigerated.

However, the heat generated in the heating portion 1a of the Stirling machine 1 must be transferred to an external means which is capable of absorbing said heat. This is the function of the second thermal energy transfer device 3, which also uses a circulating fluid to absorb the heat from the Stirling machine and to release said heat to the atmosphere or ambient air, as already mentioned above.

According to the construction illustrated in figures 1, 7, 8, 9 and 10, the second thermal energy transfer device 3 comprises a capillary pump 50 presenting an annular hermetic shell 51 provided with an external inlet 51a for the circulating fluid in the liquid state, and with an internal outlet 51b for the circulating fluid in the gaseous state and which is spaced from the inlet 51a and separated from the latter by a porous means 52, which is also annular, lodged inside the shell 51, and through which the circulating fluid flows along its path and while changing from the liquid state to the gaseous state, by the evaporation caused by a heat source placed in contact with the internal wall of the cylindrical annular shell 51, as well as by action of the pressure loss generated upon the fluid passing through the porous material.

In the construction mentioned above, the heat source is defined by the heating portion 1a of the Stirling

machine 1, around which it is affixed, in direct contact, the internal wall of the shell 51 of the capillary pump 50. The circulating fluid in the liquid state is supplied to the capillary pump 50 from a condenser 60, which is positioned at a certain distance from the Stirling machine 1, so as to transfer to the atmosphere the heat which the circulating fluid absorbed upon changing to the gaseous state in the capillary pump 50, condensing said fluid and allowing it to return in the liquid state back to the inlet 51a of the shell 51 of the capillary pump 50. The circulating fluid flows in pipes 70, 80, which connect the inlet 51a and the outlet 51b of the capillary pump 50 to an outlet 61b and to an inlet 61a of the condenser 60, respectively.

In the illustrated embodiment, the capillary pump 50 of the second thermal energy transfer device 3 presents an inlet 51a, which is disposed radially and medianly opened to an annular gap 52a defined between the porous means 52 and the external wall of the annular shell 51, in order to allow the circulating fluid in the liquid state to be homogenously supplied around the porous means 52. The opposite axial ends of the annular gap 52a are closed by the seating of the porous means 52 against the external wall of the shell 51.

In the illustrated constructive example, the annular gap 52a is obtained by the provision of an external circumferential recess in the porous means 52. It should however be understood that said recess could be also provided in the internal surface of the external wall of the shell 51.

With the construction described above, the circulating fluid in the liquid state penetrates in the annular gap 52a through the inlet 51a and starts its inward

radial path, through the thickness of the porous means 52 and while evaporating to the gaseous state, said fluid being then captured to continue its path through the outlet 51b and through the pipe 80 toward the condenser 60. For this purpose, longitudinal passages 53 are formed between the porous means 52 and the internal wall of the shell 51. Said longitudinal passages, which can be defined by grooves in the internal wall of the shell 51, are circumferentially interconnected by a channel 54, generally positioned close to one of the ends of the porous means 52 and whose interior communicates with the outlet 51b. In the illustrated embodiment, the channel 54 is defined by an internal circumferential recess provided in the porous means 52.

The internal wall of the shell 51 is shaped and dimensioned to seat around the heating portion 1a of the Stirling machine 1, in order to use the heat produced thereby to evaporate the circulating fluid arriving at the longitudinal passages 53. The heat is transferred, by conduction, from the heating portion 1a of the Stirling machine 1 to the internal wall of the shell 51 of the capillary pump 50.

The condenser 60 to be used in the second thermal energy transfer device 3 may present different constructions, provided they are adequate and compatible with the operation of the capillary pump 50.

A possible construction for the condenser 60 is the one used for the evaporator of the first thermal energy transfer device 2. In this case, the condenser 60 comprises a plurality of tubular shells (not illustrated), which are parallel to each other and transversally incorporated to a plurality of heat exchanging fins 63. The tubular shells have an end

defining an inlet 61a for the circulating fluid in the gaseous state and which is connected to the pipe 80, and an opposite end defining an outlet 61b for the condensed circulating fluid, which is already in the liquid state, after transferring the heat to the ambient air, or to any other available heat absorbing means.

Within each tubular shell flows the circulating fluid, which transfers heat to the exterior, condenses and returns to the capillary pump 50.

The refrigeration system of the present invention can further comprise a reservoir (not illustrated), associated with each thermal energy transfer device to control the working temperature by adjusting the amount of circulating fluid in each of the first and second thermal energy transfer devices 2, 3 in relation to a given amount of heat supplied to each of the capillary pumps 10, 50 of the present invention. Each circulating fluid transports heat from the hot region of the respective thermal energy transfer device to the cold region of the same thermal energy transfer device, as a function of the capillary forces generated by the difference of surface tension in relation to the temperature differential in each thermal energy transfer device.

The refrigeration system of the present invention can be further provided, although not illustrated, with a system for the dynamic neutralization of vibrations, which minimizes the transmission of the vibrations, generated by the reciprocating movement of the piston of the linear motor of the Stirling machine 1, to the shell and/or to other components to which said machine is connected. These components are mounted within the hermetic shell, which supports the components and promotes the tightness required in the compression and

expansion strokes of the gas contained therein.

The refrigeration system of the present invention provides a pumping system by capillary forces, which minimizes the difficulties of leveling the system, pipes and heat exchangers in relation to each other.

The refrigeration system of the present invention also allows achieving a high heat transfer capacity, since it presents low pressure loss, thus allowing a higher heat transfer capacity to be achieved at great distances.

Besides the advantages above, the refrigeration system of the present invention allows achieving high levels of reliability, since it does not present moving parts and is protected from vibrations.